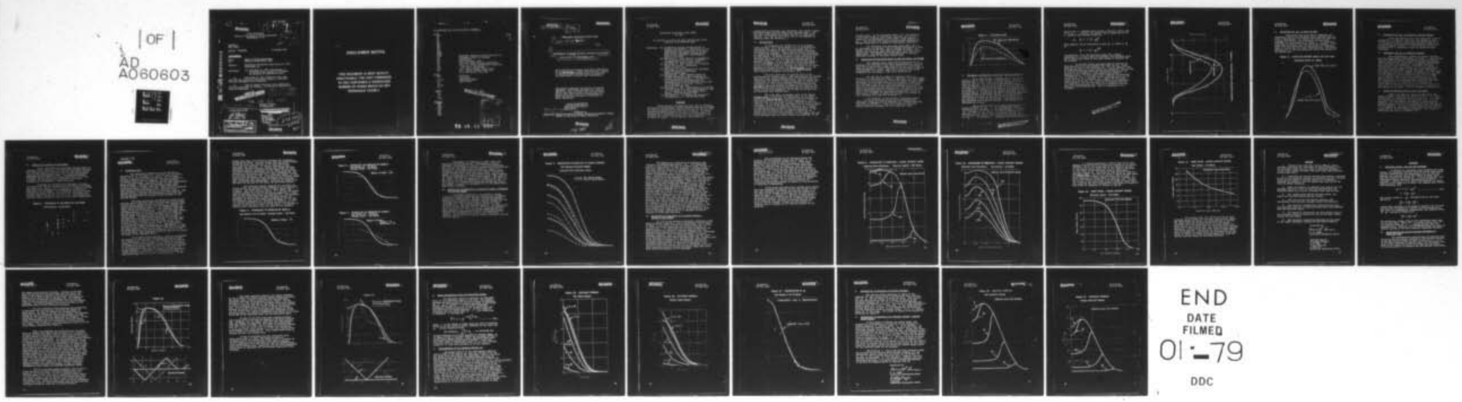
AD-A060 603 CENTER FOR NAVAL ANALYSES ARLINGTON VA OPERATIONS EVA--ETC F/G 17/9
PERFORMANCE OF AN/APS-20 RADAR AGAINST AIR TARGETS: AN ANALYSIS--ETC(U)
JUL 47

UNCLASSIFIED OEG STUDY-326 NL

| OF |
AD
A060603



END
DATE
FILMED
01-79
DDC

(J-7)

78-0396 FILE

(3)

DECLASSIFIED

D D C
NOV 1 1978
A

NAVY DEPARTMENT
Office of the Chief of Naval Operations
Washington, D. C.

Op34118-fe
(SC) A10-3

Serial: 01014P34

SEP 12 1978

3 October 1947

~~CONFIDENTIAL~~

From: Chief of Naval Operations.
To: INITIAL DISTRIBUTION LIST.

Subject: Operations Evaluation Group Study No. 326 - Forwarding of.

Enclosure: (A) OEG Study No. 326, Performance of AN/APS-20 Radar Against Air Targets: An Analysis of ComOpDevFor Data.

1. OEG Study No. 326 (enclosure (A)), prepared by the Operations Evaluation Group, is forwarded for your information and retention.

2. When no longer required, this publication should be destroyed by burning. No report of destruction need be submitted.

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

~~GROUP - 3~~
~~DOWNGRADED AT 12 YEAR INTERVALS;~~
~~NOT AUTOMATICALLY DECLASSIFIED~~

78 10 11 022

Page 22 is left blank intentionally

JERAULD WRIGHT,
By direction.

~~DOWNGRADED AT 12 YEAR INTERVALS;~~
~~NOT AUTOMATICALLY DECLASSIFIED.~~
~~DOD DIR 5200.10~~

AUTHENTICATED BY:

J. T. O'Neill
J. T. O'NEILL,
Lt. Comdr., USN

DOCUMENT DOWNGRADED TO:
Unclassified
AT THE DIRECTION OF:
OPNAVINST 5510.1E

Navy, CNO
Op03EG/sjb
Ser 377P03EG
10 May 61

002978

X78-324

28809

DECLASSIFIED

cy 101

DDC FILE COPY AD A060603

DISCLAIMER NOTICE

THIS DOCUMENT IS BEST QUALITY PRACTICABLE. THE COPY FURNISHED TO DDC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

DISTRIBUTION LIST FOR CNO SERIAL: 01014P34.

Op-30
30V
31
33
34
34D
34E
34F
34G
34H
34H4
34H6
34H7
04
40
413
05
50
50C
55R
57

BuAer
AER
R
AER-2
DR
AE
EL-80
AC

BuOrd
A
PLe
Re
Re4f

BuShips
100
424
5800
665
900
915
956

Assistant Secretary of the Navy for Air
President, Naval War College
ComOpDevFor
Navy Secretary, JRDB
Director, Naval Research Laboratory
C.O., U.S. Naval Electronics Laboratory
San Diego, California
C.O., VX-4, Quonset Point, R. I.
C.O., VCN-1, Barbers Point Oahu
C.O., VCN-2, Key West, Fla.

ComAirPac
ComAirLant
ComFAirWestCoast
ComFAETUPac

GROUP 3
DOWNGRADED AT 12 YEAR INTERVALS;
NOT AUTOMATICALLY DECLASSIFIED

ACCESSION for
NTIS White Section
DDC Buff Section
UNANNOUNCED
JUSTIFICATION
BY
DISTRIBUTION/AVAILABILITY CODES
Dist. AVAIL. and/or SPECIAL
A 23

78 10 11 022

(LO)919-47
30 July 1947

36p.

DECLASSIFIED

OPERATIONS EVALUATION GROUP STUDY

OEG STUDY [redacted]-326

101

PERFORMANCE OF AN/APS-20 RADAR AGAINST AIR TARGETS: AN ANALYSIS OF COMOPDEVFOR DATA

This publication contains classified information of an operational, rather than technical, nature. It should be made available only to those who are authorized to receive such information.

OEG Studies summarize the results of current analyses. While they represent the views of OEG at the time of issue, they are for information only, and they do not necessarily reflect the official opinion of the Chief of Naval Operations.

Center for Naval Analysis, Arlington, Va.

Prepared by
OPERATIONS EVALUATION GROUP, (formerly Operations Research Group)
Office of the Chief of Naval Operations

DECLASSIFIED

270 700

(LO)919-47
30 July 1947

OPERATIONS EVALUATION GROUP STUDY
No. 326

PERFORMANCE OF AN/APS-20 RADAR AGAINST AIR TARGET
ANALYSIS OF COMOPDEVFOR DATA

Reference:
(a) ComOpDevFor Seventh Partial Report on Project Op/V26/F42-1: "Evaluation of the Capabilities and Limitations of Airborne Early Warning Equipment (Detection and Tracking of Aircraft)", Confidential, dated 7 July 1947.
(b) OEG Study No. 313, "Methods of Evaluating the Operational Performance of Radar", Confidential, dated 4 April 1947.
(c) OEG Study No. 256, "Search and Screening: Target Detection", Restricted, dated 18 March 1946.
(d) OEG Study No. 265, "Search and Screening: Radar Detection", Restricted, dated 19 April 1946.
(e) ComOpDevFor Fifth Partial Report on Project Op/V26/F92-1 and Amendments to Project Op/V31/A16-3(17): "Evaluation of the Capabilities and Limitations of Airborne Early Warning Equipment (Detection of Camouflaged Schnorkel)", Secret, dated 10 February 1947.
(f) OEG Study No. 307, "Performance of AN/APS-20 Airborne Radar in Search for Camouflaged Schnorkel - Analysis of ComOpDevFor Data", Secret, dated 20 January 1947.
(g) OEG Report No. 56 "Search and Screening", Confidential, dated 20 February 1947.

ABSTRACT

Both tracking and detection runs made by Squadron VX-4 against conventional fighter aircraft have been analyzed to give the probability of detection in each of two tactical situations, direct approach and passing course. On direct approach, 50% probability of detecting a single fighter is attained at 45 miles; the Sweep Width for a passing course is about 130 miles. The two factors which limit the

OVER →

probability of detection and, therefore, both warning radius and Sweep Width, are sea return and relative speed. The data are extrapolated to predict results for high speed targets, i.e., 600 to 1500 knots, and the limitations on scanning radar are discussed.

1. Introduction

In evaluating the performance of an airborne radar in search for a given target, one is interested in estimating the chance of detecting the target with the equipment in question in each of the tactical situations of operational interest. These tactical search situations can usually be treated as one of two types, direct approach or area search. In direct approach we are interested in detecting the target by the time the range has closed to any given value, R, i.e., in detection probability as a function of range. On any given track of an area search, we are interested in the probability of detection while target and search craft are passing each other at any given distance of closest approach, or lateral range, i.e., in detection probability as a function of lateral range. These cases are discussed in reference (b).

The tests were made by Squadron VX-4 of the Operational Development Force. They were designed to provide data from which these probabilities of detection could be determined; the details of these tests, and the results and conclusions obtained from them are described in detail in reference (a). The primary concern of this study is the methods of analysis employed in obtaining the results, and the influence which these methods had on the design of the tests; the trials themselves, the results and conclusions are described only briefly here.

The trial runs, in general, were of two types: tracking runs to determine the performance of the radar itself; and detection runs to determine the performance of radar and operator together (see reference (a)). There were two main sets of tracking runs, differing chiefly in emphasis. In the first set, the object was to track a target consisting of 2VF or 2VA aircraft over as great a distance as possible between a minimum and a maximum range, using various combinations of AEW and target altitudes. In the second set, the object was to study the effect of one variable at a time on the performance of the radar, with all other variables held as nearly constant as possible. On all

tracking runs, ψ, the blip/scan ratio, i.e., the fraction of the radar scans on which blips appeared, was taken as a measure of the performance of the radar. This quantity, ψ, was measured for various ranges between minimum and maximum under each of a number of operational conditions.

The detection runs were made using 2VF's, 2VA's, or equivalent, as targets. The AEW planes maintained a short patrol, from 40 to 50 miles long, parallel to shore. The targets were vectored away from land until they were beyond radar range. The planes were instructed then to attempt undetected passage of the short patrol line.

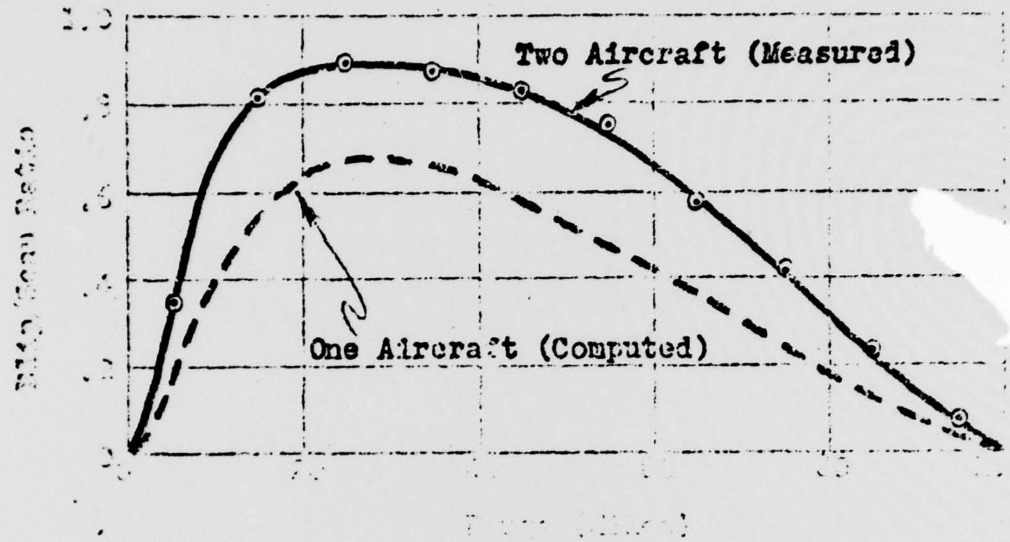
2. Dependence of Blip/Scan Ratio on AEW and Target Altitudes.

The original data, presented as enclosure (C) to reference (a), show that while large fluctuations are observed from run to run within a range band little or no systematic trend is apparent. Within the accuracy of the tests, there is no dependence of blip/scan ratio upon either AEW or target altitudes over the range of altitudes investigated.

For the lowest altitude combination shown, AEW aircraft at 1,000 feet and target at 500 feet, the radar range, as limited by radar horizon, is only 68 miles; yet the average blip/scan ratio is above zero out to 120 miles. Furthermore, the blip/scan ratio for ten mile range bands above 63 miles does not differ from those for other altitude combinations within the accuracy of the measurements. The reason for this rather surprising result is believed to have been the occurrence at low altitudes of "anomalous transmission" during a large enough fraction of these runs to bring the average up (see reference (a), page 22, paragraph 5).

The variation of the fraction of effective scans, ψ, with range is computed from all the tracking runs recorded in enclosure (C) of reference (a), indicated by the solid line in Figure 1. This is the curve on which the various analyses presented in this report are based.

Figure 1. BLIP/SCAN RATIO



3. <u>Dependence of Blip/Scan Ratio on Number of Aircraft.</u>

In a given tactical situation the target to be detected may consist of one or many aircraft. If these aircraft come in from positions widely separated in either range or azimuth, they will appear as separate, single aircraft targets. On the other hand, if they are flying in a formation, the total extent of which in any direction is less than 1 or 2 miles, they will appear as a single target. To determine ψ for each of the various possible numbers of aircraft making up the target by direct test would require a prohibitive amount of flying effort. It is desirable, therefore, to develop an equation by means of which ψ for any given number of aircraft can be predicted from the data obtained with a single aircraft. This equation is developed as follows:

The blip/scan ratio for a target consisting of a single aircraft is ψ, and ψ' is that for a target consisting of n aircraft. We are interested in obtaining ψ' in terms of ψ and n. The chance that a single aircraft will produce a blip on any given scan is ψ, the chance that a single aircraft will not produce a blip is $1-\psi$. If there are n aircraft, the probability that

none of the n aircraft will produce a blip on a given scan is $(1-\psi)^n$. Finally, the chance that at least one of the n aircraft will produce a blip is

$$(1) \quad \psi' = 1-(1-\psi)^n$$

This equation can be rearranged to give ψ in terms of ψ' as

$$\psi = 1-(1-\psi')^{1/n}$$

Consequently, given the blip/scan ratio for a target consisting of a given number of aircraft, the blip/scan ratio for a target consisting of any other number of aircraft can be computed.

In the VX-4 tests, runs were made to compare the blip/scan ratio for one aircraft with that for two. These data can be used to test Equation (1). The two aircraft flew in formation with the third sufficiently separated from the two to produce independent blips on the screen, yet not so far away as to be unescorted. Both targets were tracked simultaneously. The blip/scan curves obtained are presented in Figure 2. The broken line is the blip/scan curve for two planes computed from equation (1). Except for one point which seems to be off, this computed curve is in reasonably good agreement with the two plane curve obtained directly. The differences observed are those to be expected from the averaging procedures employed. This is discussed in the Appendix.

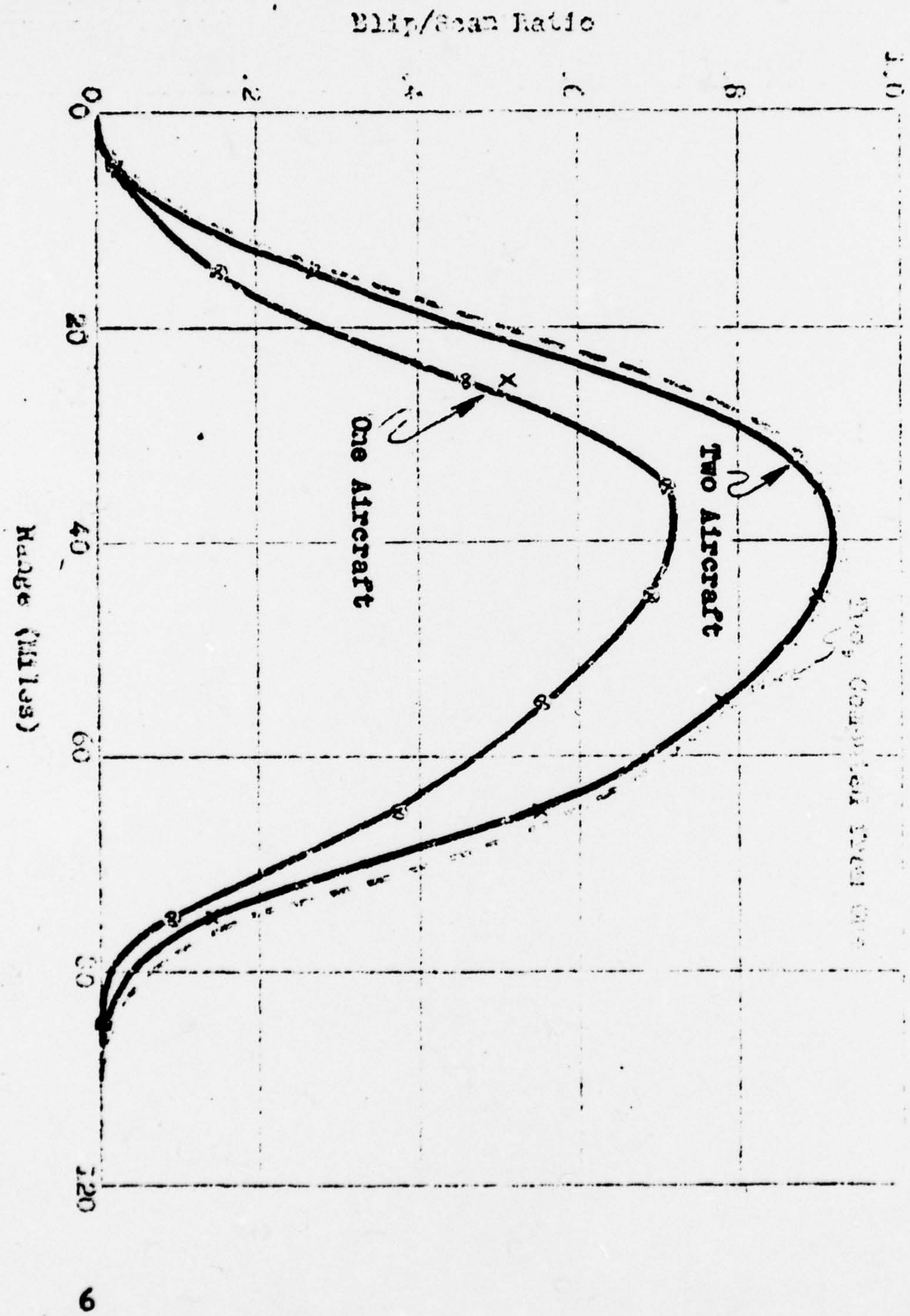


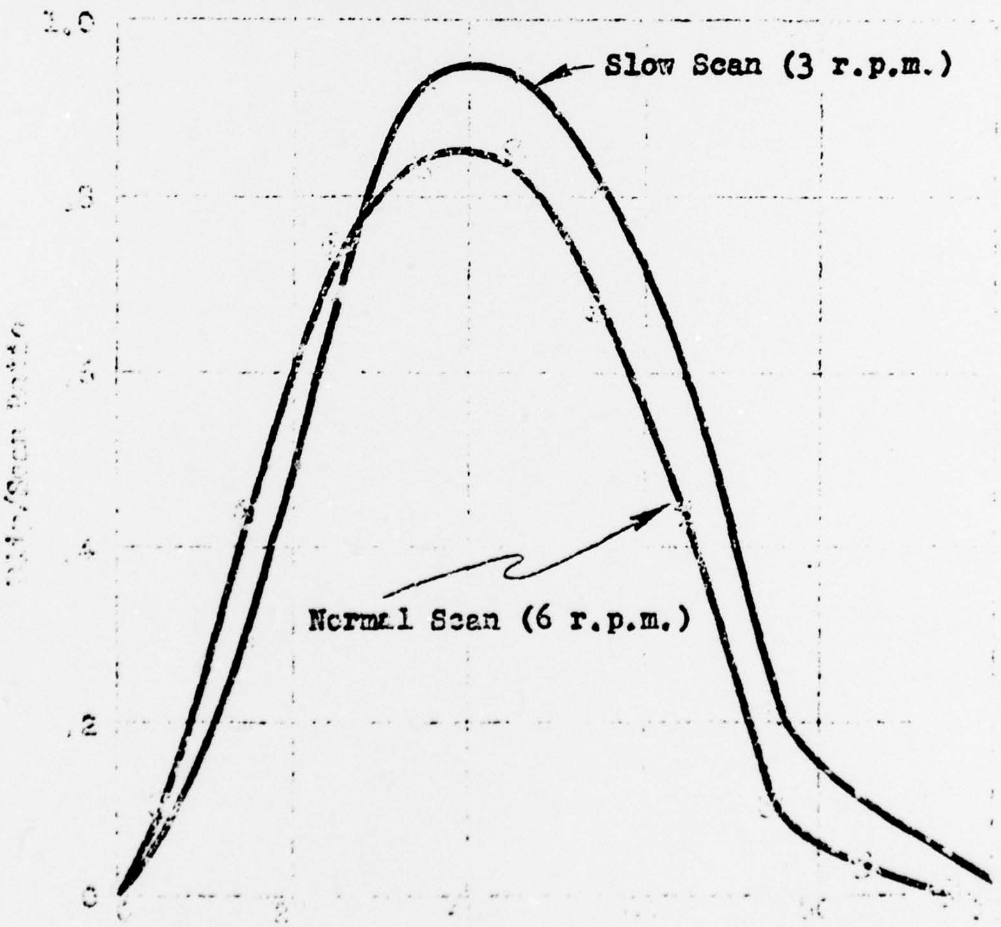
Figure 2. BLIP/SCAN RATIO COMPARISON RESULTS

4. Dependence of ψ on Rate of Scan.

Comparative runs were made to determine the difference between the blip/scan ratio obtained with the normal scanning rate of 6 sweeps per minute and that with 3 sweeps per minute. The comparative results from reference (a) are reprinted in Figure 3. No theoretical relationship between these two curves is proposed. It is clear from the curves that at long ranges the blip/scan ratio is higher for the slower scanning rate. The weaker signals tend to build up during the added time allowed by the slower scan.

Figure 3. COMPARISON BETWEEN NORMAL AND SLOW SCAN

Blip/Scan Ratio vs. Range



DECLASSIFIED

(LO)919-47
30 July 1947

5. Dependence of ψ on Radius of the Sea Return.

Since the tracking runs were made under "tracking conditions", special circuits were used freely to track through the sea return. Therefore, the dependence of ψ on sea return, to be expected under detection conditions, was not measured directly. The effect of sea return on detection will be considered later in connection with detection.

6. Dependence of ψ on Special Circuits.

The AN/APS-20 has a number of special circuits for the suppression of sea return and other sources of noise. Runs were made to compare the blip/scan ratio at various ranges, using any one of a number of circuit combinations, with that using the receiver in a standard condition (70% gain and no special circuits). The number of circuit combinations tested was so large that it was possible to make only a small number of runs with each combination, five runs with the given circuit combination and five under the standard condition. Because of smallness of the data samples obtained, no definite conclusion could be drawn. The indications were that all the circuits tested were useful for tracking through clutter, but that only one, STC (sensitivity time control), was useful for detection. This results from the fact that the improvement in performance inside the sea return is obtained only at the expense of the blip/scan ratio outside the sea return in all except the one case. For more detail see reference (a).

7. Effect of Altitude on Standard Sea Return.

During the detection runs, the sea return was always recorded under the same standard set of conditions, 70% gain and no special anti-clutter circuits. On a number of flights, the sea return was measured at more than one altitude. It was possible, therefore, to determine the extent to which the sea return depends upon the altitude of the AEW aircraft. It was concluded that, within the errors to be expected in the tests, the sea return varies with the square root of the AEW aircraft altitude. This point is discussed more fully in reference (a).

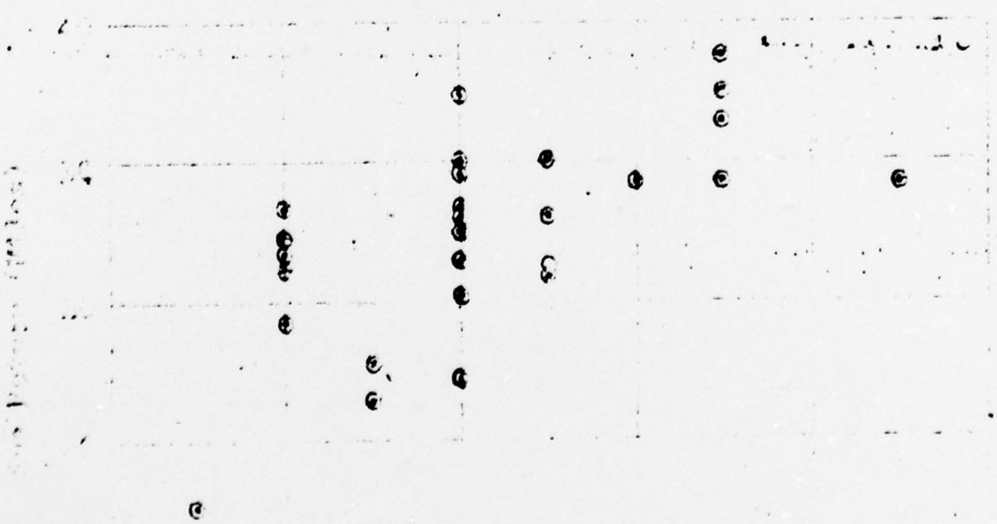
8. Effect of Sea State on Sea Return.

Having determined the dependence of sea return on altitude, it was possible to eliminate the altitude variable, and to determine the extent to which the sea return depends upon the sea state as estimated from the air and recorded according to the Beaufort Scale. When several aircraft estimated the same sea, they seldom differed by more than one unit. It can be assumed, therefore, that these estimates are consistent to within one unit.

In Figure 4, reprinted from reference (a), the sea return with the AEW aircraft at 1,000 feet is presented for various sea states. The scatter in the points is greater than that to be expected on the assumption of errors in estimating the sea state. It is concluded that while there is some correlation between sea state and sea return, the Beaufort Scale does not describe all the characteristics of the sea which contribute to the sea return for S-band radar.

Figure 4. DEPENDENCE OF SEA RETURN ON SEA STATE

AEW Altitude 1,000 Feet



(LO)919-47
30 July 1947

9. Detection Runs.

The individual detection runs are listed in enclosure (D) of reference (a). They were all made using 2VF's, 2VA's, or equivalent, as target. The tactical situation selected for test was that of direct approach of the target toward the AEW aircraft. The AEW aircraft could not stand still, nor could it use its radar effectively while orbiting. Therefore, it patrolled a short line, 40 or 50 miles in length, while the target attempted undetected passage across this line. The analysis considered each run as a direct approach of the target to some representative or average position of the AEW aircraft. The details of this procedure are described in reference (a); the justification for it is given in the Appendix of the present report.

The three operational variables considered in the analysis of the detection data were altitude, target speed, and the radial extent of the sea return. The tracking runs showed that altitude of either AEW or target aircraft as such had no consistent effect on the blip/scan ratio and, hence, could not be expected to affect detection over the altitudes included in the tests. The range of target speeds was not great enough to permit analysis of the effect of target speed; the average speed of 155 knots was used in the analysis. The data were analyzed in three groups according to the extent of the sea return: runs for which the sea return was between 0 and 25 miles, 25 and 50, and 50 and 75 miles. In each of the first two groups, the probability of detection by range, R, was taken as the quotient of the number of detections at and beyond R, and the total number of runs in the group. For the third group, an effective, rather than the actual, number of runs in the group was used. This effective number of runs and the reason for using it are described below.

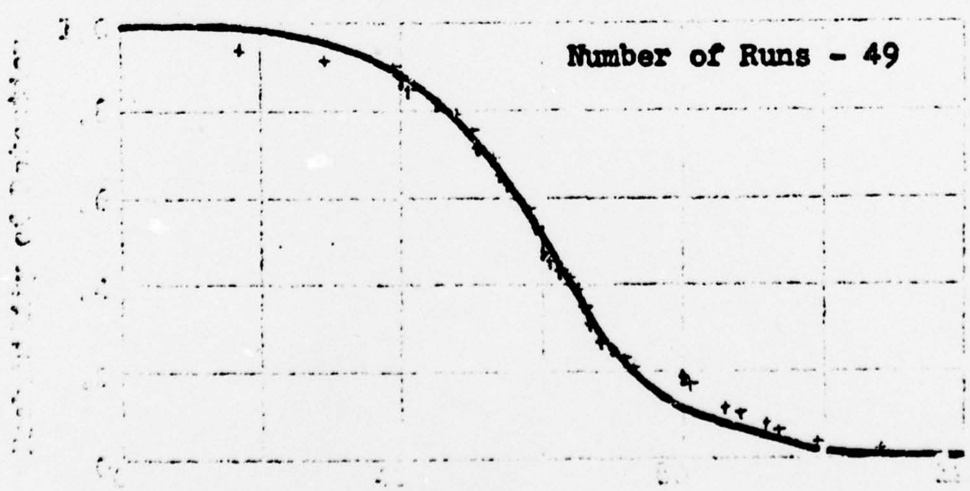
On a number of the flights in which the sea return was between 50 and 75 miles, the first few runs resulted in no detections. Rather than waste flying effort with no detections under these conditions, the flight was usually continued at a more favorable altitude (smaller sea return). On a number of similar flights, the first few runs resulted in some detections, and the flight was continued at the higher altitude. While this procedure was conservative of flying effort, it tended to bias the results in favor of peak performance of both equipment and personnel. To get

around this bias, the following procedure was employed in analyzing the data. For each flight with sea return between 50 and 75 miles, the fraction of the runs which were successful was computed. An average fraction of runs successful was then computed, giving each flight the same statistical weight, regardless of the number of runs made. The total number of detections for the whole group was then divided by this average fraction of runs successful to give an effective number of runs. This effective numbers of runs, greater than the actual, can be thought of as including these runs which would have been made had flight been continued when conditions were unfavorable. There was no evidence of any bias for the runs in the other two sea return groups.

The detection results obtained for the three sea return groups are reprinted from reference (a) in Figures 5, 6, and 7. The solid line in each of these figures was computed, using the blip/scan ratio, ψ , and p_o, the chance that an operator will see a given blip presented on a given scan by the method described in reference (b). The arguments on which the calculation is based are given briefly in reference (b) and in more detail in references (c) and (d). The blip/scan data used are presented in Figure 1. A value of 0.05 was selected for p_o as giving the best fit of the detection data for sea return 0 to 25 miles. The details of fitting these particular data are given in the Appendix.

Figure 5. PROBABILITY OF DETECTION BY RANGE R

Sea Return 0 to 25 Miles Average Speed - 155 Knots



DECLASSIFIED

(LO)919-47
30 July 1947

Figure 6. PROBABILITY OF DETECTION BY RANGE R
Sea Return 25 - 50 Miles
Average Speed - 155 Knots

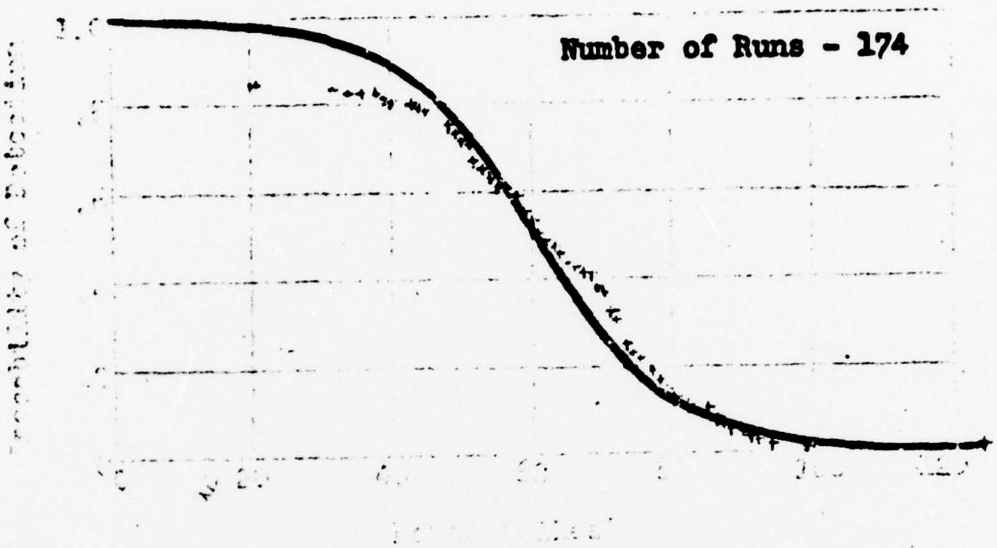
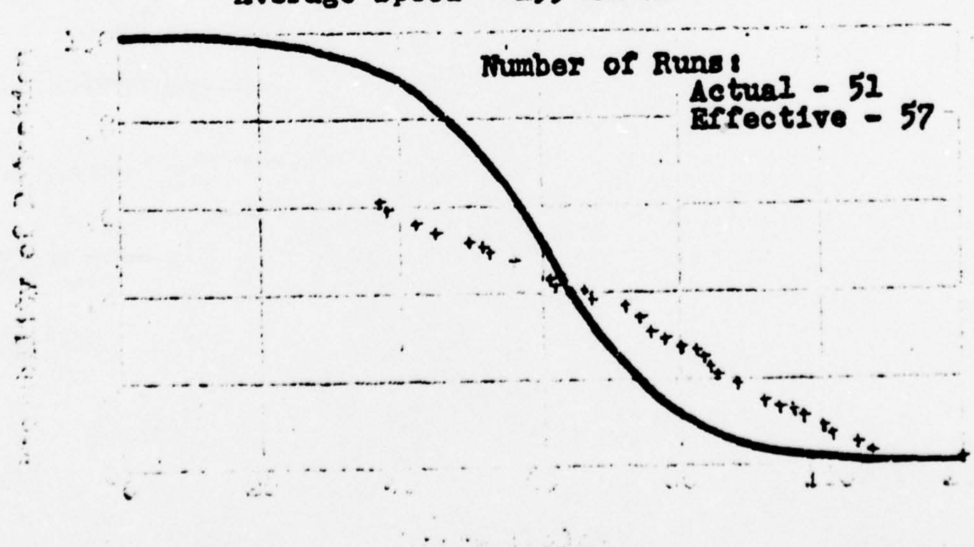


Figure 7. PROBABILITY OF DETECTION BY RANGE R
Sea Return 50 - 75 Miles
Average Speed - 155 Knots



Examination of Figures 5, 6, and 7 shows few detections in the sea return. Furthermore, there is evidence, particularly in Figure 7, that more detections are made at great ranges than are predicted from computations based on the blip/scan curve of Figure 2. This is not surprising when we remember that the calculations assume uniform search effort over the entire scope. If the sea return is extensive, the search effort is no longer uniform but is concentrated in the long-range region. The value of p_o which best fits the data, 0.05, is about twice that for the snorkel target, as described in references (e) and (f). This agrees with operational experience indicating that an air target is easier to distinguish on the PPI scope than a snorkeling submarine.

10. <u>Probability of Detection on Direct Approach - Influence of Relative Speed</u>.

As stated in Section 9, the spread in target speeds in the actual tests was not great enough to warrant analysis by target speed. However, the direct approach curves can be computed for various relative speeds from the blip/scan ratio using the blip/scan theory outlined in reference (b). The resulting curves for one and two aircraft targets are presented in Figure 8. The first three pairs of curves, for 200, 400 and 600 knots are reprinted from reference (a). These are useful operationally for determining the probability of being intercepted without warning. The fourth pair of curves, for 1500 knots relative speed, has been added in order to provide a glimpse into the future.

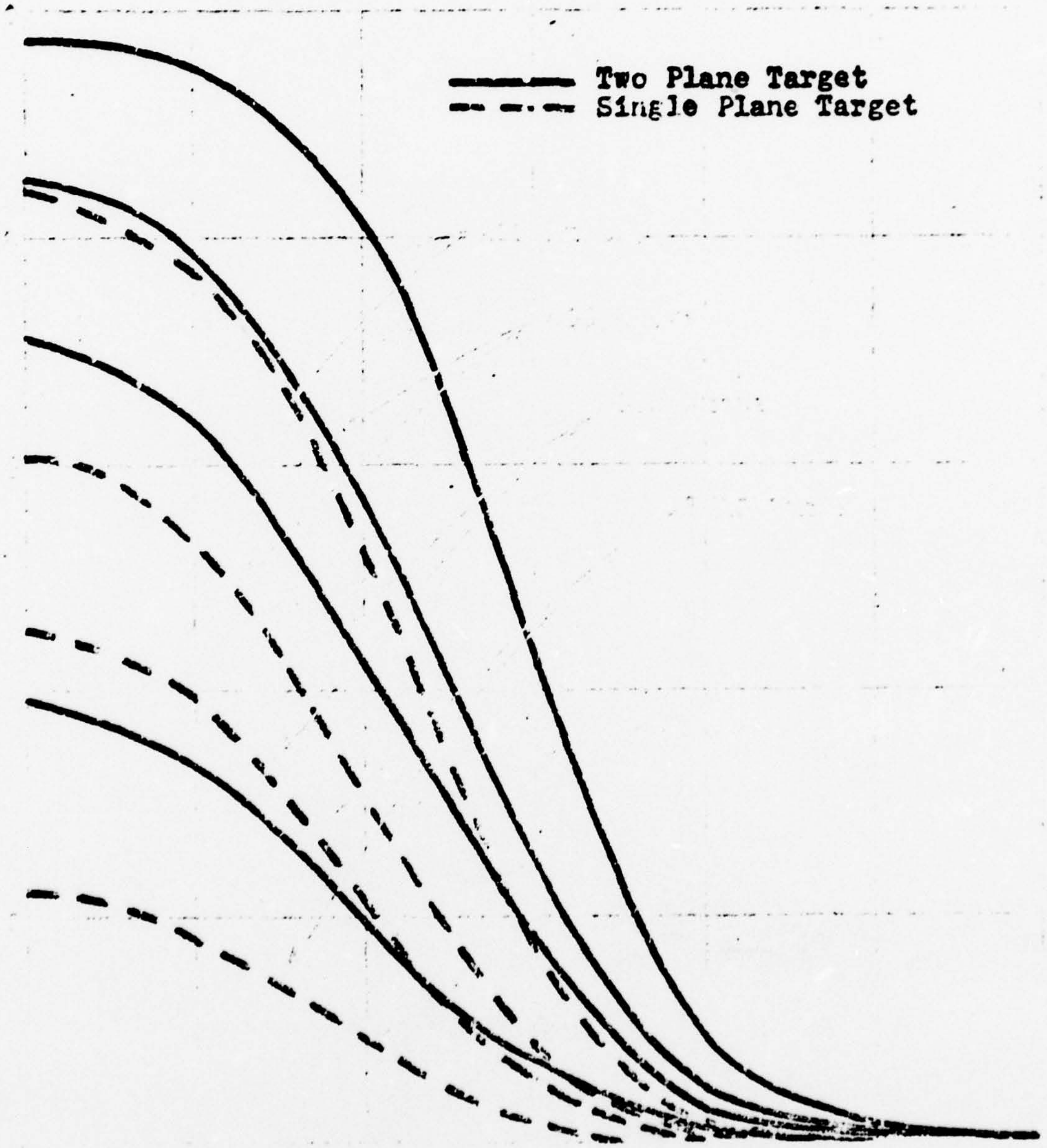
DECLASSIFIED

(LO)919-47
30 July 1947

Figure 8. PROBABILITY OF DETECTION ON DIRECT APPROACH

FOR VARIOUS RELATIVE SPEEDS

Computed from Blip/Scan Ratio



The decrease in probability of detection with increase in relative speed arises from the decreasing number of radar scans per mile of relative track, as can be seen from Equation (2a) of the Appendix. At first sight, one might hope to improve the situation by increasing the radar scanning-rate. In this connection there are two serious difficulties which could not easily have been foreseen. Reference to Figure 3 shows that a reduction in scanning rate below the standard 6 r.p.m., leads at long ranges to an improvement in the blip/scan ratio, i.e., the fraction of the scans on which blips appear. Hence, an increase in radar scanning rate beyond the standard 6 r.p.m. can be expected to lead to a reduction in the blip/scan ratio. At first sight this does not appear serious if the total number of blips presented shows a net increase. However, the low value of 0.05 for p_o, the probability that the operator will see a blip if it appears on any given radar scan, indicates that even the ten seconds between scans allowed by the standard rate of 6 r.p.m. does not permit the operator to search the scope thoroughly. Increasing the scanning rate will further decrease the time per radar scan permitted for visual search, so that p_o may well decrease in proportion to the reciprocal of the scanning-rate. In view of the evidence of scanning loss even at 6 r.p.m., and the physiological limitations of the radar operator, it would appear that there is little or no hope for any great gain in detection probability to be realized through an increase in radar scanning-rate.

11. Probability of Detection on a Passing Course - Lateral Range Curves.

In most of the tactical air-search situations which arise in actual operations, one is interested, not in direct approach of the target toward the search plane, but in cases in which the target passes at some minimum distance, or lateral range. The cumulative probability of detection for each lateral range cannot be obtained directly from the detection runs because these runs were designed for a different tactical situation, that of direct approach. It can be computed, however, using the blip/scan theory and the value of p_o obtained from the direct approach runs (See Reference (b)). While the result obtained is a computed one, sufficient confidence can be placed in it to eliminate the need for laborious detection runs to determine it directly. The details of the computations and the raw materials from which this probability can be computed for cases other than those given here are presented in the Appendix.

The computations to be discussed assume the validity of the blip/scan theory and the value of p_0 obtained from the direct approach runs. Three other assumptions are made to yield conservative estimates. First, the primary data of Figure 1, while taken under tracking conditions, do not represent zero sea return conditions. It is assumed that they do; this assumption is conservative. It is assumed that no detections can be expected in the sea return, and this assumption is believed to be very nearly true; in any event, it is conservative. It is further assumed that if the sea return is extensive, there is no improvement due to concentration of search effort at long ranges. In view of the evidence of improvement shown, particularly in Figure 7, this assumption is definitely conservative.

On the basis just described, lateral range curves have been computed as examples to show the effects of the two main variables, sea return and relative speed, i.e., the speed of the target considering the AEW aircraft as fixed in space. In Figure 9, a typical relative speed of 200 knots has been selected and the curves computed for various sea returns. In Figure 10, a typical sea return of 20 miles has been selected and curves computed for various relative speeds. Curves for other cases of interest can be computed by the methods outlined in the Appendix.

Figure 9. PROBABILITY OF DETECTION - SINGLE AIRCRAFT TARGET

Computed from Blip/Scan Relative Speed - 200 Knots

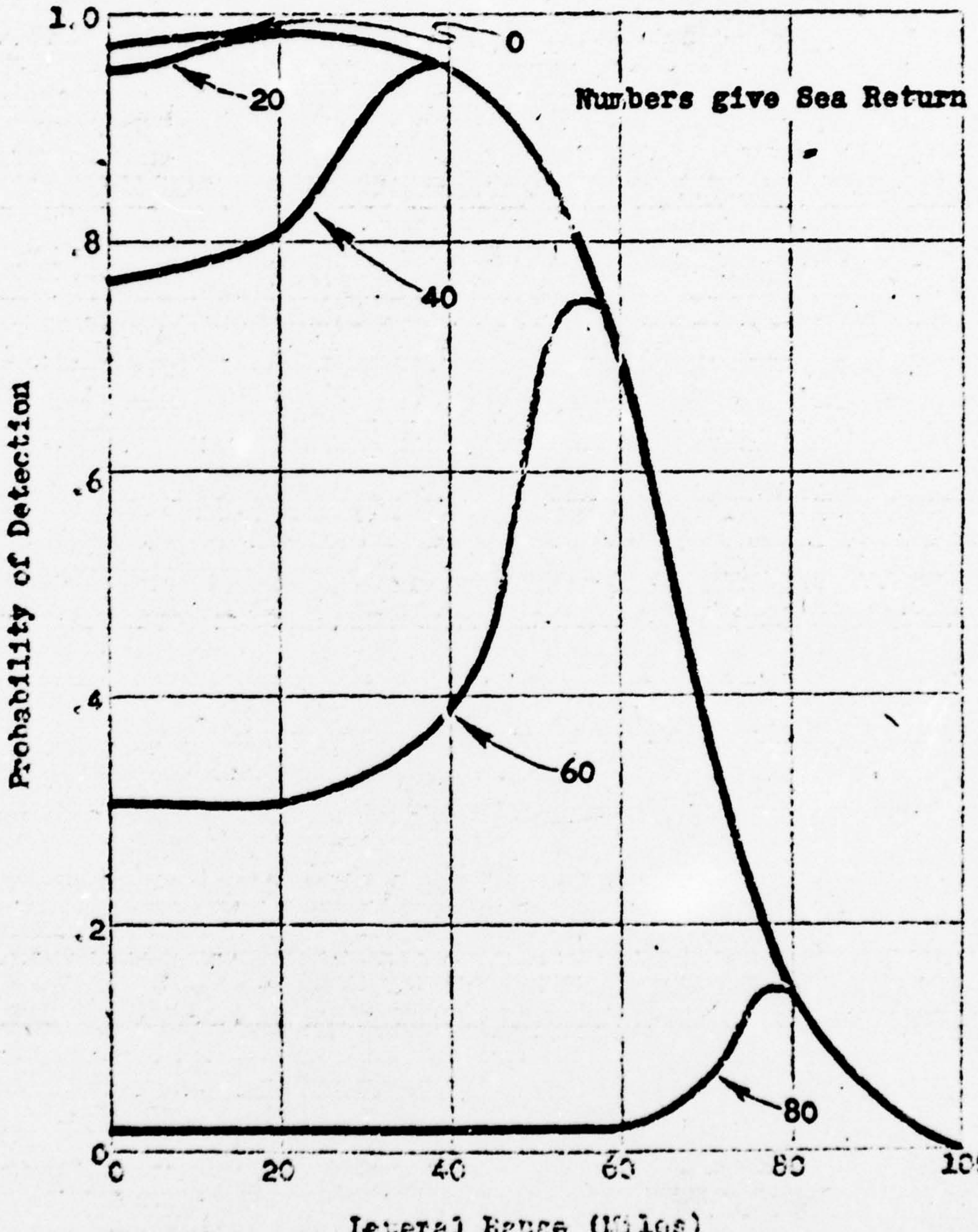
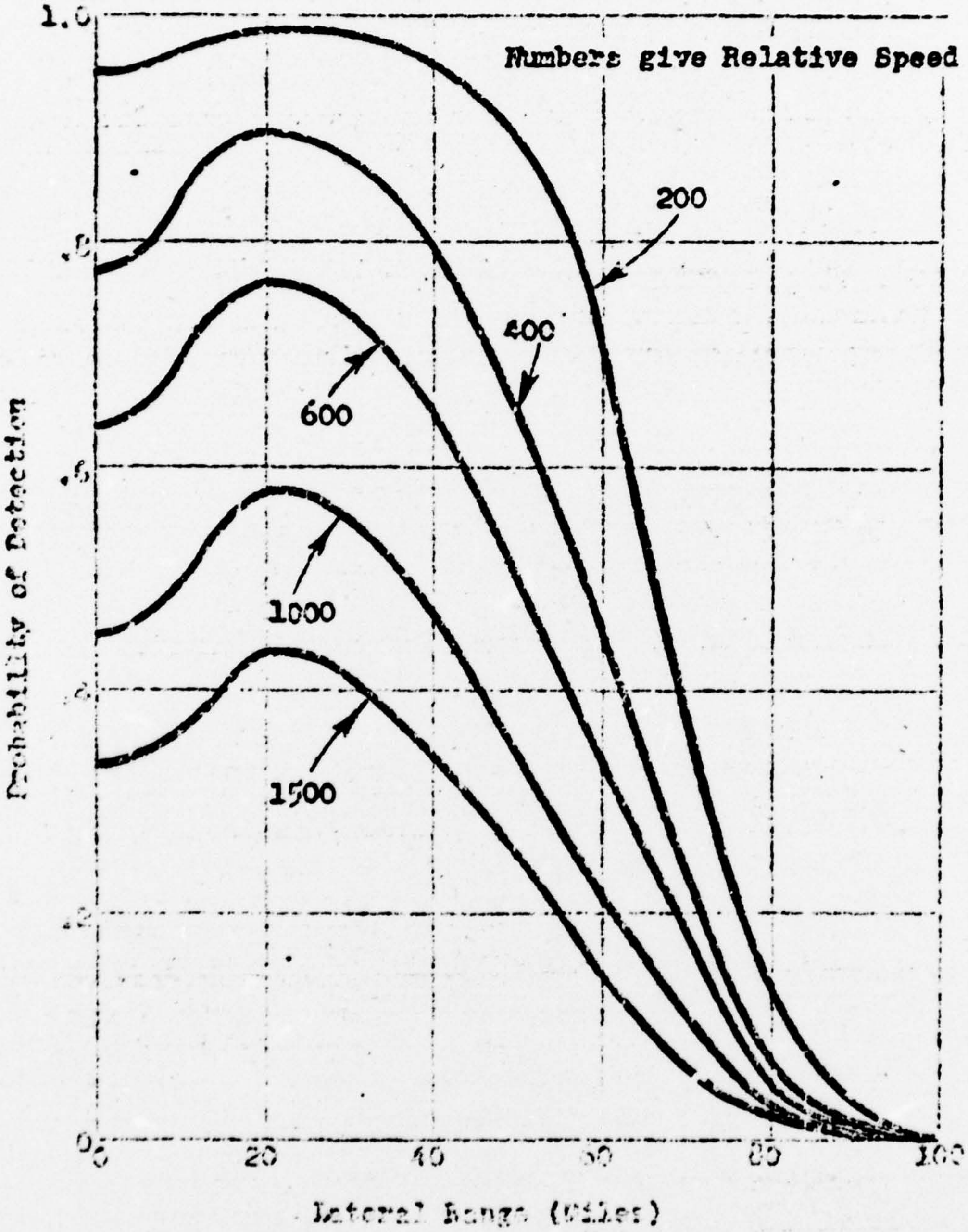


Figure 10. PROBABILITY OF DETECTION - SINGLE AIRCRAFT TARGETS

Computed from Blip/Scan   Sea Return - 20 Miles



DECLASSIFIED

In search situations in which there is no overlapping of search effort on successive tracks of the search aircraft, one is not interested in the detailed structure of the lateral range curve, but in the width of the strip on both sides of the aircraft, which is effectively searched completely. The width of this strip is known as the Sweep Width. Its value is given by twice the area under the lateral range curve, once for each side of track. A brief discussion of Sweep Width is given in reference (b), and in more detail in Chapter 5 of reference (g). To show the effect of sea return and relative speed on Sweep Width, this quantity has been computed from the curves of Figures 9 and 10 and is presented in Figures 11 and 12.

Figure 11. SWEEP WIDTH - SINGLE AIRCRAFT TARGETS

Relative Speed - 200 Knots

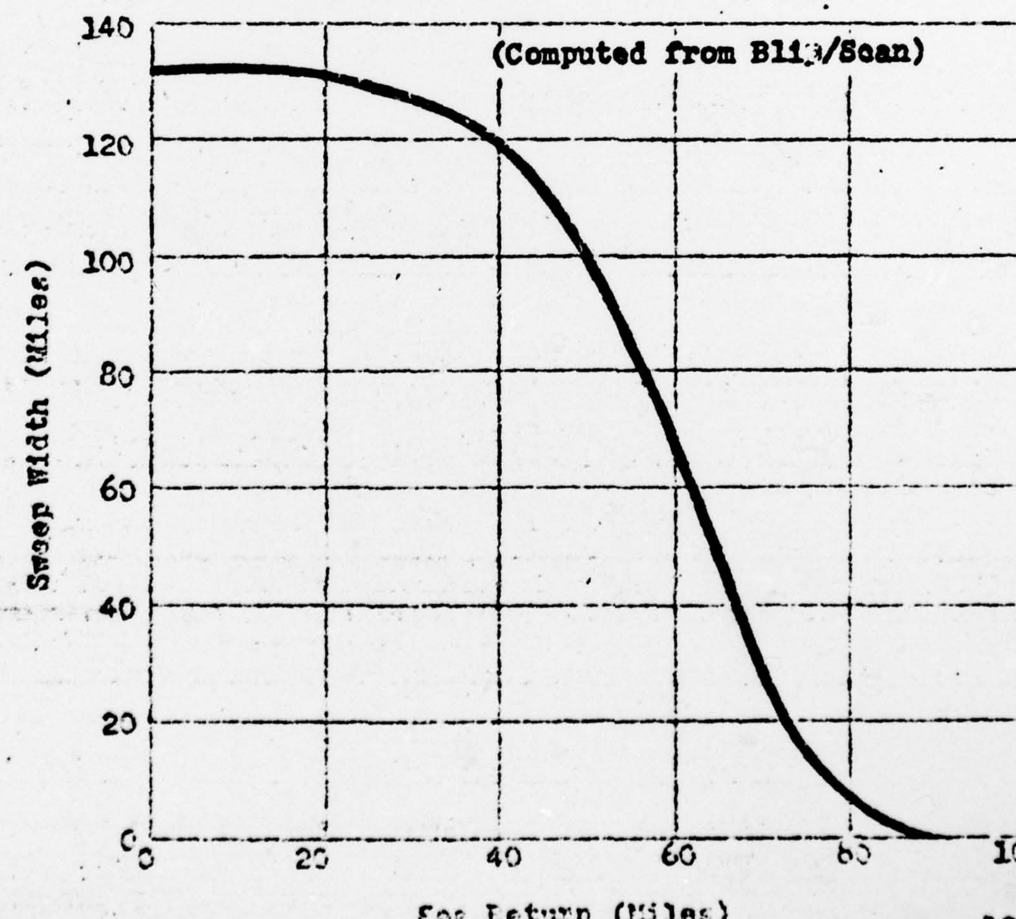
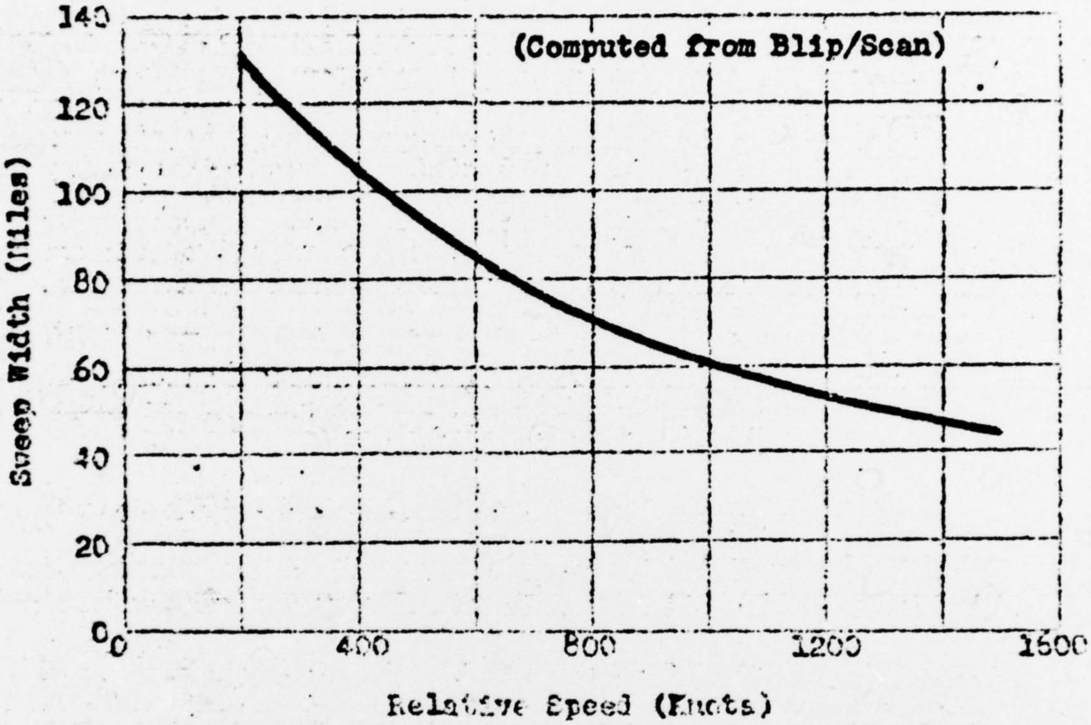


Figure 12. SWEEP WIDTH - SINGLE AIRCRAFT TARGETS

Sea Return - 20 Miles



It is quite clear from Figures 11 and 12 that increases in sea return and relative speed greatly reduce the Sweep Width and, hence, the effectiveness of search. For single aircraft it would appear that sea return extending out to 40 miles will not seriously affect the Sweep Width; beyond this point sea return becomes extremely important. Little can be done with scanning radar against high speed fighters. The effect of speed on Sweep Width, shown in Figure 12, demonstrates the advantage to our own forces of using high speed aircraft against an enemy who employs scanning radar for detecting aircraft.

(LO)919-47
30 July 1947

CONFIDENTIAL
DECLASSIFIED

SUMMARY

1. Tracking runs show that neither AEW nor target altitude influences the percentage of scans effective, i.e., the blip/scan ratio over the range of altitudes included in the tests (target altitudes 500-4,000 feet, AEW altitudes 1,000-10,000 feet).

2. Comparison of tracking results for targets consisting of one and two aircraft permits the prediction of the blip/scan ratio for any number of aircraft making up a formation, provided the formation does not extend more than one or two miles in either direction.

3. There is evidence of scanning loss even at the low scanning rate of 6 r.p.m. as shown by the fact that the blip/scan ratio for 3 r.p.m. is greater than that for six.

4. All special anti-clutter circuits tested are useful for tracking through the sea return.

5. Only one of the anti-clutter circuits, STC (sensitivity time control), appears useful for detection.

6. The detection probabilities determined directly from detection runs are in good agreement with those computed from the blip/scan ratio.

7. The detection probability for both direct approach and a passing course is reduced if part of the track passes through the sea return.

8. The detection probability decreases as the speed of the target increases, keeping the AEW speed constant.

Submitted by:

Edward S. Lamar

E. S. LAMAR,
Operations Evaluation Group.

Computations by:

Dorothy Riggle

D. RIGGLE

Elaine Marcuse

E. MARCUSE
Operations Evaluation Group.

APPENDIX

1. Blip/Scan Ratio - One and Two Aircraft.

In Section 3, reasonably good agreement was shown between the measured blip/scan ratio for a two plane target and that computed from the measurements for one aircraft. However, the computed values were higher at every point than the measured one (Figure 2). It is believed that this discrepancy arose because of the averaging procedure employed. Assuming for the moment that Equation (1) holds exactly for any given run in which both targets were tracked simultaneously, then

$$\psi' = 1-(1-\psi)^2 \quad \text{- - - - - - - - - - -} \quad (1a)$$

$$= 2\psi - \psi^2 .$$

The average value of ψ', obtained from all the runs, should be

$$\overline{\psi'} = 2\overline{\psi} - \overline{\psi^2} .$$

Rather than computing as indicated by Equation (1) for each run and then averaging the results, we have averaged and then made the computation; consequently, the computed value of ψ' plotted in Figure 2 is

$$\overline{\psi'} = 2\overline{\psi} - \overline{\psi}^2 .$$

The difference between this and the expression above lies in the last term. Since $\overline{\psi^2}$ is always greater than $\overline{\psi}^2$ the computed value of ψ' is always greater than the measured value. However, the discrepancy seems too small to justify the use of the more elaborate averaging procedure.

2. Justification for Direct Approach Treatment of Detection Data.

The justification proposed here for treating each detection run as a direct approach to some average position of the AEW aircraft makes no claim to mathematical rigor. It is simply employed to indicate that, for the patrol line used in the tests, the errors introduced are not large. If it were possible to maintain the AEW aircraft stationary,

the target could approach directly. Because of the fact that the AEW aircraft is patrolling back and forth, the track of the target relative to the search craft is not direct, but is broken into a zig-zag line. We propose to show that the probability of detection for this zig-zag track is not appreciably different from that for the direct approach. The direct approach track will be known as the equivalent track in the following discussion.

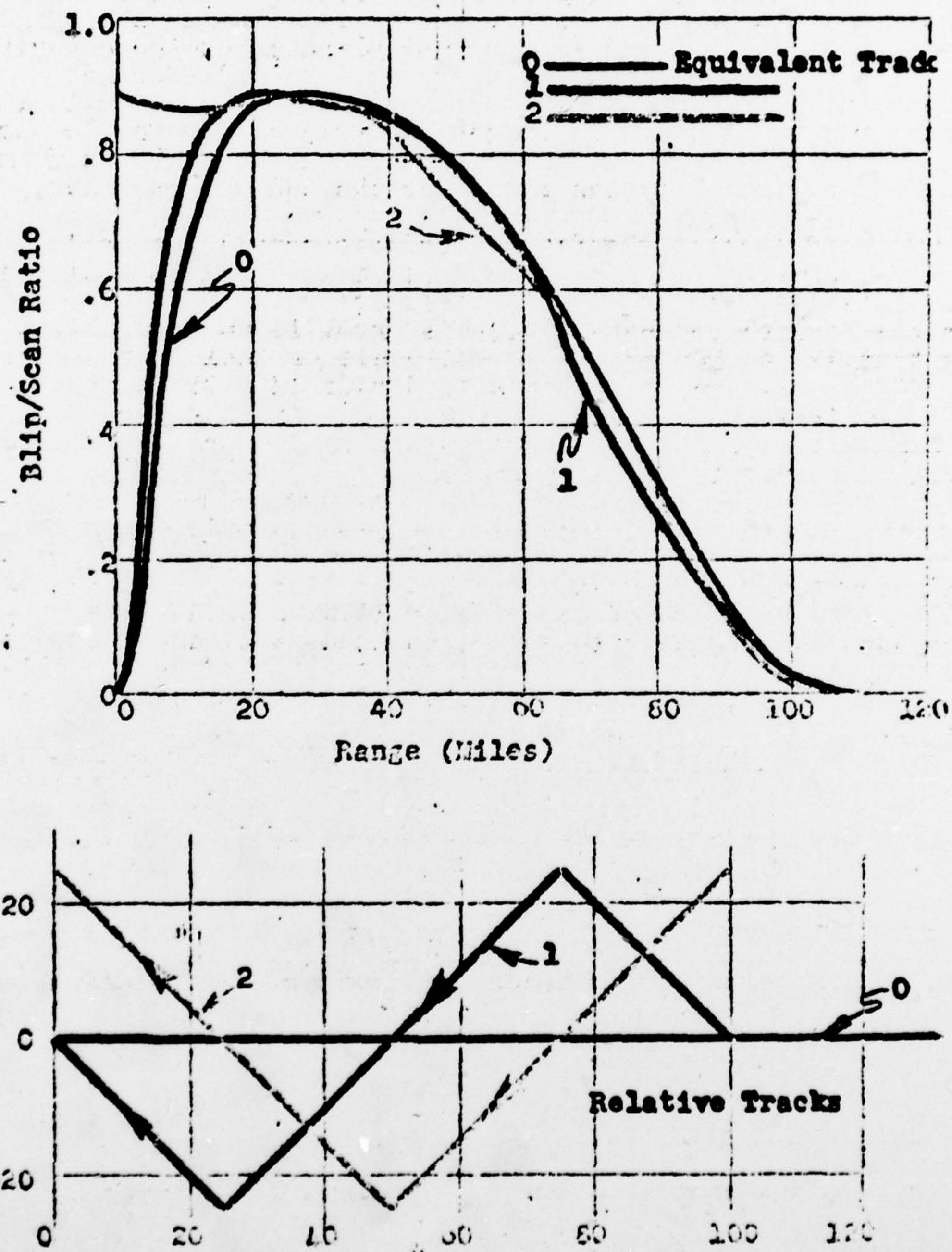
The two quantities which determine the probability of detection are the blip/scan ratio and the number of radar scans. In order to compare the probabilities of detection for the direct and the zig-zag tracks, the blip/scan ratios for the two tracks at points corresponding in time and, hence, in number of radar scans, will be compared. If for these corresponding times the blip/scan ratios are equal, it will be assumed that the probabilities of detection are also equal. The blip/scan ratio data used are those for a two plane target, obtained from Figure 1.

There are available for comparison many possible pairs of tracks, from which critical ones will be selected. In order to determine which pairs of tracks are critical, the various methods by which the target might approach the patrol line must be considered first. He can approach anywhere between normal and grazing incidence. For normal incidence, it may be discerned that, for any two corresponding points, one on the actual track and one on the equivalent, the range to the AEW plane from the point on the actual track is always equal to, or greater than, that from the corresponding point on the equivalent track. If the equivalent rather than the actual track is used, there will always be a systematic error. For grazing incidence, the range to the AEW plane from the point on the actual track may be either greater than, or less than, the range from the corresponding point on the equivalent track. If the equivalent rather than the actual track is used, the errors which occur in the individual runs will tend to average out. Therefore, the critical situation, examined in the following paragraphs, is that of normal incidence in which there is a definite systematic error.

The most probable normal incidence case is one in which the target attempts undetected passage across the center of the patrol line. Figure 13 presents the two limiting cases (along with that of equivalent track) where: (1) the AEW plane is at the center of the patrol line when the target crosses, and (2) the AEW plane is at the end of the patrol line. Beyond 20 miles, there is little difference between them, and the systematic error does not seem serious; the ranges within 20 miles are of little interest.

DECLASSIFIED

Figure 13.

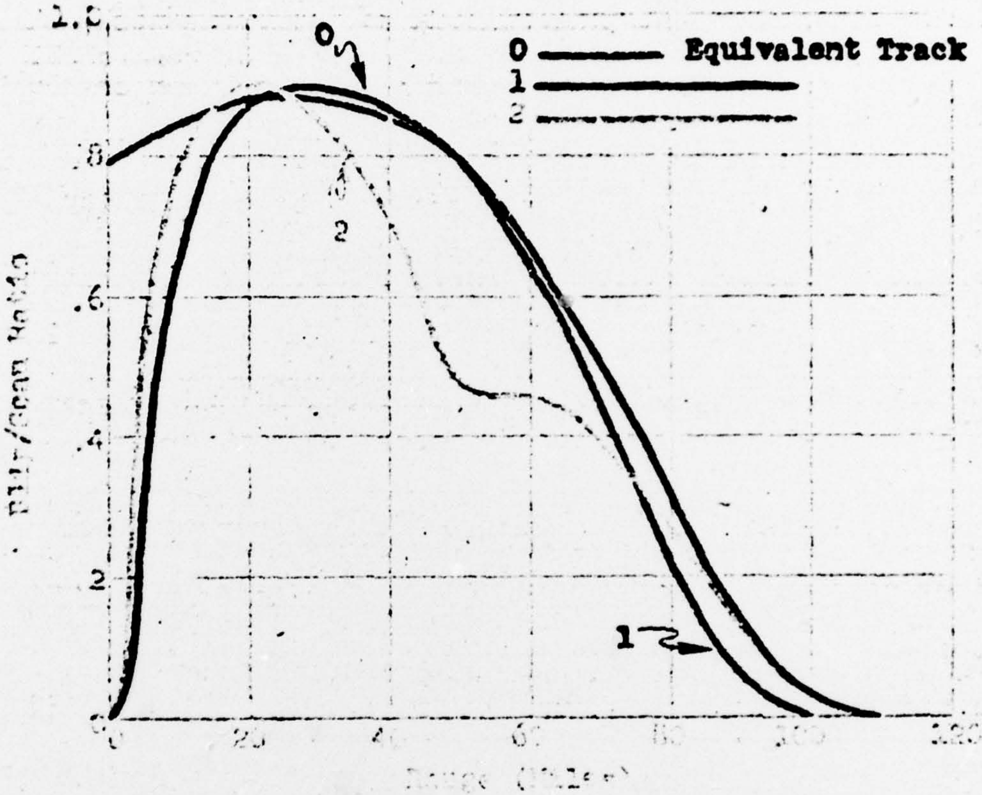


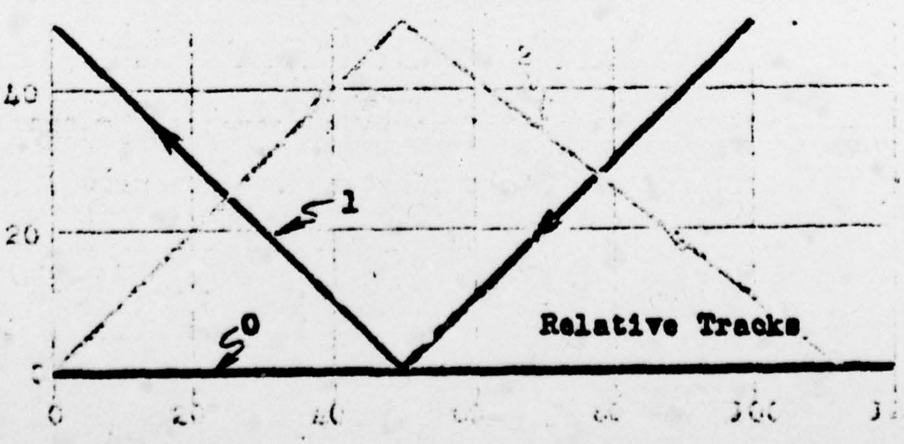
The least probable situation for normal incidence is one in which the target attempts passage across the end of the patrol line. Figure 14 presents two limiting cases (together with that of equivalent track), where: (1) the AEW plane is at the same end of the patrol line as the target at time of crossing, and (2) the AEW plane is at the opposite end. For the first instance, there is little difference between the actual and the equivalent path beyond 20 miles; for the second case, there is considerable difference in the blip/scan ratio, the maximum difference which occurs at 50 miles being 40% of the blip/scan ratio for the equivalent track.

If each of the four cases were equally probable, the average error which has its maximum at 50 miles would be 12%. Actually, the two latter cases are much less probable than the former; consequently, this error is considerably less than 12% at 50 miles. As the angle of incidence changes from 90° to 0°, the error tends to divide into two parts: a systematic error which becomes 0 at 0°, and a random error which reaches its maximum at 0°. This random error tends to average out over the various runs.

It may be concluded that any systematic error which occurs over all runs, regardless of angle of incidence, point of crossing the patrol line, or position of the AEW plane at time of crossing, will have an average value considerably less than 12%, and that the random errors will tend to average out. Therefore, the use of an equivalent target track is justified for the accuracy required in this analysis.

Figure 14.


0
Equivalent Track
1
2
1.0
.8
.6
.4
.2
0
20
40
60
80
100
120


2
1
0
Relative Tracks
40
20
0
20
40
100

3. Basic Computations from the Blip/Scan Theory.

The blip/scan theory of detection is described fully in the references given in the text. For present purposes we shall select the following frame of reference. Let x be the distance of nearest approach, known as the lateral range, and let y be the other orthogonal coordinate, measured parallel to the relative track and from the point of nearest approach. In this frame of reference, for any given value of x, the probability of detection P is given by

$$P = 1 - e^{-np_0\int_{\infty}^{y}\psi^2 dy} \quad \text{------ (2a)}$$

where n is the number of radar scans per mile of relative track, p_0 is the operator factor described in the text, and ψ is the blip/scan ratio.

The integral, $\int_{\infty}^{y}\psi^2 dy$, is presented for various distances of closest approach or lateral range, x, in Figure 15 for a two plane target and in Figure 16 for a single plane target (Figure 1 gives blip/scan ratio data from which these integrals were computed.) Since the blip/scan ratio is symmetrical about $y = 0$, only positive values of y have been included in the two figures.

4. Determination of the Operator Factor, p_0.

The actual fitting of the experimental curve to give a value of the chance, p_0, that the operator will see any given blip, was done in the logarithm. Log Q = log (1-P) was computed from the direct approach detection data of Figure 5, and the negative of this was plotted in Figure 17. The ordinates of the curve for $x = 0$, (Figure 15) i.e., direct approach, were then multiplied by a constant to give the best fit in the intermediate range band; this process is represented by the solid line of Figure 17. The factor required was 0.116 = np_0. The average speed was 155 knots; accordingly there were 0.387 minutes per mile. The scanning rate was 6 r.p.m.; therefore, n, the number of scans per mile, was 2.32. Solving for p_0 gives 0.05. Except in the region where sea return can be expected to reduce the results below those computed from the blip/scan ratio, the fit is quite satisfactory. The one point off the curve at 29 miles can not be taken too seriously because of random fluctuations to be expected in such a small sample of data.

DECLASSIFIED

Figure 15. BLIP/SCAN INTEGRAL

Two Plane Target

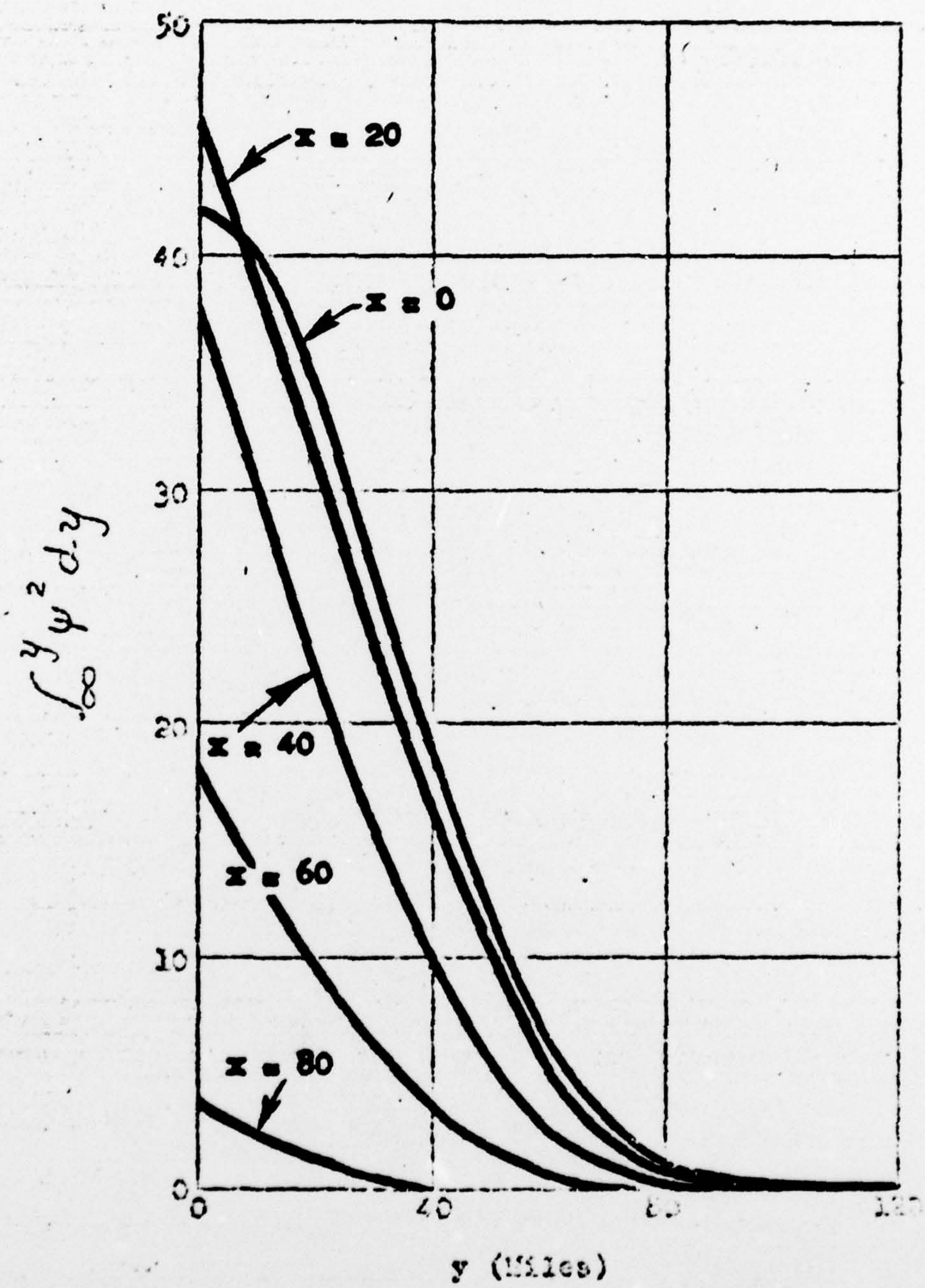


Figure 16. BLIP/SCAN INTEGRAL

Single Plane Target

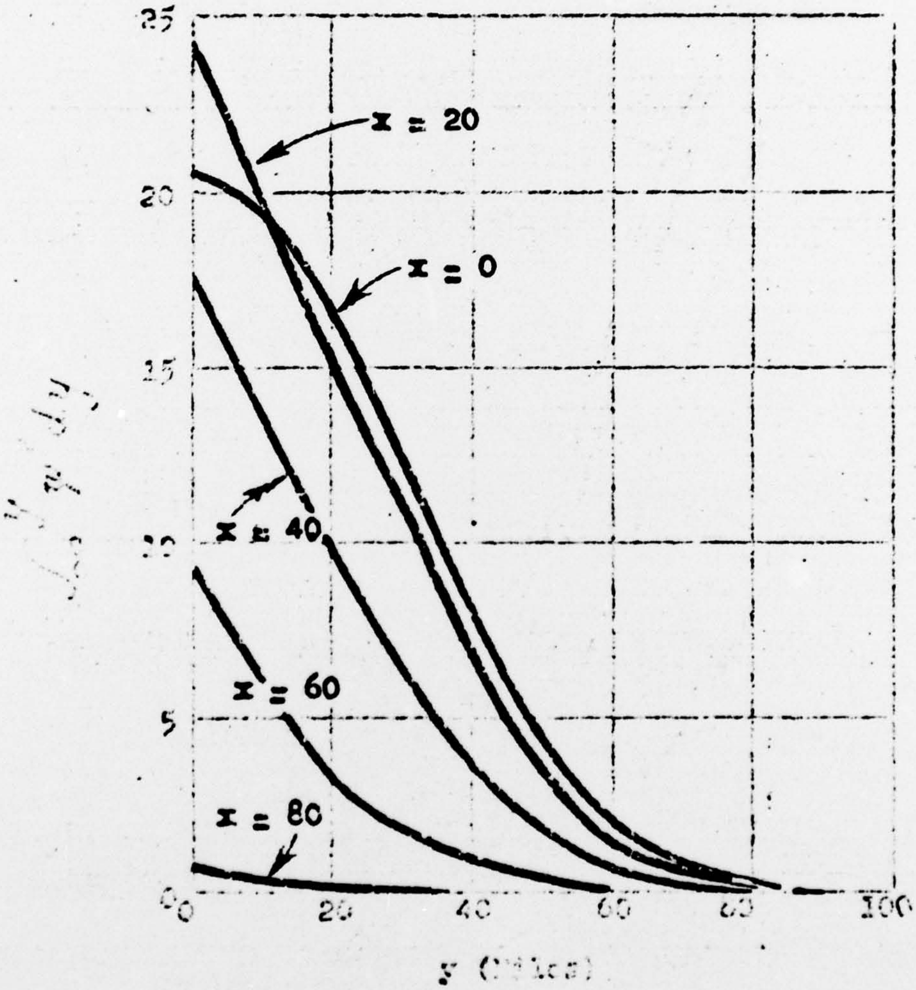
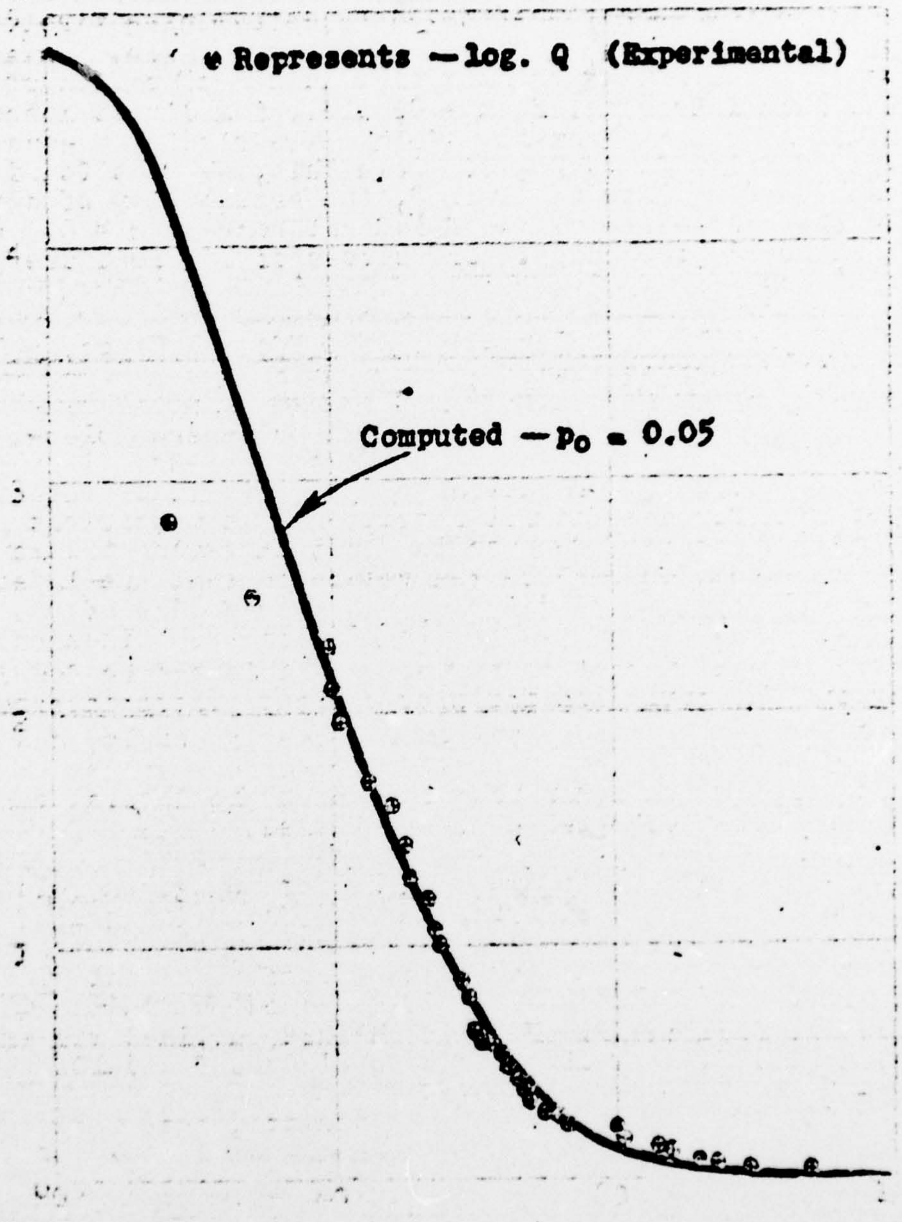


Figure 17. DETERMINATION OF p_0

Sea Return 0 to 25 Miles



5. Probability of Detection on Direct Approach.

The various curves presented in Figure 8 were computed for each target speed by determining first the product of p_o and the number of scans per mile. This product was then multiplied by each of a number of values of the blip/scan integral for $x = 0$, i.e., for direct approach, as obtained from Figures 15 and 16. The result of each computation gives a value for $- \log Q$. From this, Q was found and subtracted from unity to give P, the probability of detection. For the particular value of lateral range, $x = 0$, y becomes equal to R, the range. The curves of Figure 8 are plotted as functions of range, R.

6. Probability of Detection on a Passing Course - Lateral Range Curves.

If the target is passing the search plane, the probability of detection as a function of the distance of closest approach, or lateral range, x, is of interest. To find this for any lateral range, x, we must first find the blip/scan integral for use in Equation (2a). Assume that there are no detections in the sea return so that the integral extends from infinity to the value of y at the edge of the sea return, y_o, and from minus y_o to minus infinity. Since the blip/scan ratio is symmetrical in range, R, this can be found by doubling the integral from infinity to y_o. These integrals have been arrived at directly from Figures 15 and 16, and the results are given in Figures 18 and 19 for various values of sea return. These are the basic curves from which the lateral range curves for any relative speed can be obtained.

The value of $- \log Q$, for any given relative speed, can be found by multiplying the blip/scan integral for the appropriate lateral range and sea return by the product of p_o and n, the number of scans per mile. Finally, the probability of detection, P, is obtained by finding Q and subtracting from unity. The method just outlined was employed to provide the examples given in Figures 9 and 10.

Submitted by:

Edward S. Lamar

E. S. LAMAR
Operations Evaluation Group

Dorothy Riggle

D. RIGGLE
Computer
Operations Evaluation Group

Figure 18. BLIP/SCAN INTEGRAL

Two Aircraft Target

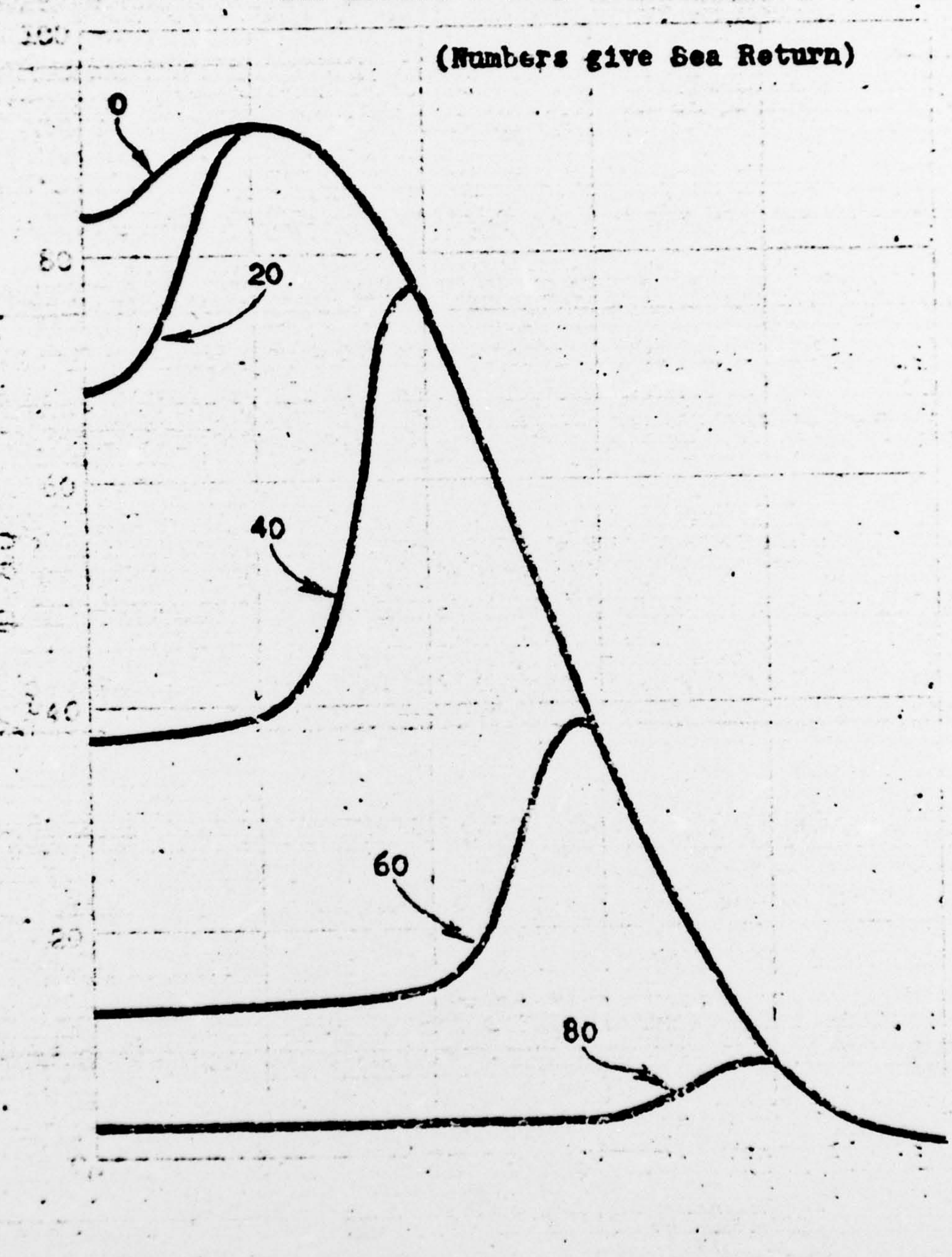


Figure 19. BLIP/SCAN INTEGRAL

Single Aircraft Target